Design and Analysis of Electric Vehicle Charger with Power Factor Correction

SHORT SYNOPSIS

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CERTIFICATE

I hereby declare that the short synopsis "Design and Analysis of Electric Vehicle Charger with Power Factor Correction" being submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy in Electronics & Communication Engineering under faculty of Engineering& Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2022-2023.

It is a Bonafide record of original work carried out under the supervision of Dr. Vimlesh Singh (Associate Professor, FET, MRIIRS). The work has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free, and proof has been submitted.

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ABSTRACT

The world is rapidly using its reserves of natural fossil fuel amongst which the automobile industry is the fastest user. Along with the deletion of fossil fuel it has led to global warming. There is dire need to move from the use of fossil fuels to alternative fuels to run the vehicles. Electricity powered vehicles are proving to be a boon for the same cause. For the efficient working of electric vehicles, there is need of efficient storage devices such as fuel cells, solar cells, batteries, ultra-capacitors etc. Rechargeable Batteries are most used energy storage devices used in EV industry. As the batteries are to be charged after the power from them is drained, there comes the use of Electric Vehicle battery chargers to charge the EV battery. EV charging can be classified into 3 different levels of charging. Level-1 is the slowest level of charging common in North America and Japan, level-2 is available in most of Asia and Europe and little faster than level-1 charging, and 3rd level is fastest DC charging and the most expensive one too. There are different categories of EV chargers i.e. On-board chargers and Off-board chargers. Off-board chargers need specific infrastructure and high input power supply to charge the EV batteries directly through DC supply. Whereas the On-board chargers do not need special infrastructure for charging an EV except for the Electric Vehicle Supply Equipment, which supplies the AC to the EV's On-board charger to further charge the EVbattery. The continuous research is going on for long ranged EV batteries. With the development of fast and long-range batteries, there is a need for fast and affordable PFCs for the chargers. The PFCs would control the harmonics produced in the circuit at AC-DC or DC-DC stage of chargers. The PFCs would keep the input current in phase with input voltage so the power factor of the circuit would remain almost 1, which is practically not possible so the nearest desirable output is 0.95 power factor. Implementing IOT at PFC level would help to control and monitor the circuit even better.

Keywords: EVcharger, PFC EV charger, IOT EV charger

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1. INTRODUCTION

Presently, all kinds of businesses and services like hospitality, defence, manufacturing, transportation, and digital services are based on energy. To produce energy, fuel is required which is usually in the form of oil or coal. Major user of oil as a source of energy is the transportation industry. Transportation industry is responsible for almost 50% of global oil consumption along with 25% of global Greenhouse Gas Emission. In the past two decades, the global level of Carbon dioxide (CO_2) emission has increased tremendously and a major contribution in this emission increase is the transportation industry. The demand of vehicles is continuously increasing and so is the need of energy to run the vehicles. In the next decade the transportation sector is expected to increase the vehicular population by at least two times.

Increased use of energy will lead to depletion of fossil fuels quickly along with environmental deterioration by releasing disastrous pollutants. A dependable source of energy is needed to run the vehicles which do not have any or less disastrous effect on the environment. Electric energy is proving to be the best alternative to oil energy for the transportation sector.

Research Focus

The increase in Greenhouse effect and pollutant level has led to serious change in climate. Battery technology has advanced a lot. Thus, technological advancement and concern to save both environment and fossil fuel have persuaded the global electric vehicle (EV) makers to introduce more EV models. The level of green-house gas emitted by EVs is very less than that by internal combustion engine (ICE) models.

To promote EVs, most of the countries are providing users with special kinds of incentives like tax relaxations, special parking lots. The major concern for the user is the limited range of fully charged batteries. Usually, the range of the EVs fall between 100 km to 700 km. Higher the range, the higher is the size of the battery. Charging of the battery also depended upon the type and the charging capacity of the charger. Generally, chargers are classified into two categories on the basis of their charging current as AC Charger and DC Charger. The batteries of EVs are to be charged with DC. The AC charger receives AC power from the AC outlet and converts into DC to charge the EV through Battery Management System (BMS). The DC charger directly provides the battery with DC power to charge.

Furthermore, chargers can be classified into two categories based on their installation namely On Board and Off Board Charger. The On-Board charger, an AC charger, is usually small in size and has lower output. On Board Charger can further be divided into two sub-categories- Built in vehicle or hand-held AC Charger. The built charger is pre-installed into the EV such

that only power from the AC supply needs to be connected to it and it directly starts charging the EV by converting AC to DC inside the EV. The handheld charger is available or sold with the vehicle which when connected to AC supply starts converting AC into DC outside the body of the EV and charges the EV.

The power output of an onboard charger ranges from 3 KW to 22KW which can charge the vehicle from 30 kWh to 60 kWh in 6 to 14 hours depending upon the combination used.

Off board chargers are DC chargers which are usually faster as compared to AC chargers. The charger is wall mounted or fixed chargers which directly provide AC current to BMS of vehicle to charge the vehicle. The Off-board chargers are high output power chargers. The output power ranges from 40 kWh to 200kWh.

History of EV

Electric Vehicles (EV) were introduced first in the mid-19th century. Batteries used to run the EV were disposable which resulted in lots of dead batteries. Gradually by the beginning of 20th century as electrification of houses paced up developments were done in the field of rechargeable batteries and the EVs batteries started to get charged rather than dumping dead batteries. The batteries were removed from the vehicle and moved to the charging station to charge. Later telephone boxes look-alike, water, and weather- proof, public chargers were set up by General Electric around the major cities of the US. The battery range of EV was not even 100 kilometres, so the trend of EV declined around 1960s as road quality was improved and ICE vehicles were cheap and so was Gasoline.

Modern EV was re-started by Toyota by building Toyota Prius, a hybrid electric car and the opportunity was widely used and commercialised by Tesla after releasing the first Tesla model S in 2012. Now Tesla is setting up charging stations all over America and in some other countries.

Though DC chargers are fast chargers, regular charging on fast chargers or charging on the charger that has more capacity rate than the battery deteriorates the life of the battery. Therefore, charging with On-board is preferable than on the fast charger.

2. LITERATURE REVIEW

Being the most emerging field, a lot of work is going on in this field. This section will be a brief overview of the EV chargers.

A. Blinov, et. al. (2022) have described a new rapid electrical vehicle (EV) charger setup that may be used with a straight medium voltage (MV) link. The concept is described as a multi boost (MCB) design, which offers flexibility, minimal line inductance needs, high-frequency isolator, and efficient semiconductors consumption. Rather than employing a 2-stage conversion strategy, in which each cell has a power factor correction (PFC) converter followed by separated dc converters, a single-stage converting method is used.

A. K. Tiwari and L. K. Sahu (2022) have suggested that the suggested five-levels of rectifier is made up of six switching devices that can provide five different voltage levels, reducing filters and improving voltage stability. The rectifier's control strategy and operational phases are described in depth. The rectifier can provide unity power factor for any and all voltage levels and controlled active power at the charging station with the controlling system in place.The suggested rechargeable battery pack is able to achieve high effectiveness, making it appropriately used in conjunction with the grid system.

A. Verma and B. Singh (2019) have presented a multi-objective, three-phase solar Photovoltaic array-based grid integrated off board EV charger. They have demonstrated and tested the dual mode i.e., stand alone and grid connected mode for EV charger to act as power backup for household load and charging the EV respectively. They have also verified the capacity to operate in over/under voltage conditions. They have also verified the capacity to operate in over/under voltage conditions. The proposed charger acts stable in both the modes and in transition from stand-alone mode to grid connected mode.

Akhila V and et.al. (2022) have analysed the utilisation of a microprocessor, relays, and RF receiver, the researchers have created a straightforward charging point for electrical vehicles that may facilitate charging for the customer's vehicle. A customer may greatly facilitate charge at a charging point with the help of such a RFID charging stations authorisation system. The suggested approach is better than the current one since it enables charger clearance to happen automatically as soon as an Electrical Vehicle arrives and because it doesn't involve any other parties. By installing an RFID system at the charging point, which allows for automated authorization, this strategy will save operating time. This system will have a very wide operating frequency thanks to the RF transmitter and the receiver.

B. Bhad and K Khengre (2021) have suggested that with Internet of Things, consumers are now shifting to renewable technology, as seen in the rising demand for electrical automobiles. The Place to Charge the car has become one of the most prevalent issues as the number of Electric Vehicles in our community rises. Therefore, a smart charger with Internet of Things capabilities is developed in this research for charging electrical vehicles quickly and effectively while also calculating energy usage utilising the Mongoose OS or the Arduino IDE and many sensors. The adoption of Internet of Things-enabled gadgets for use in everyday lives, such as security, health, or the industrial sector, is made possible by dramatic changes in industrial automation, connectivity, and latest developments in cloud services.

C. Wei, et.al. (2019) have described a 6.6 kW bi-directional SiC MOSFET-based Electrical Vehicles (EV) on-board charging. The electric vehicle (EV) transportation market is rapidly expanding as the globe advances towards greener sources of fuel. A 6.6-kilowatt bi-directional On-Board Charging on SiC MOSFET is built and analysed in this study. For On-Board Charging, the DC-link voltage range is tailored at 385V to 425V, based on a typical battery charge ranging between 250V to 450V. The next work will focus on improving the transformer's temperature control in order to limit the temperature increase.

H. Kim, *et.al* (2022) have stated that considering universality of input and broad voltage level, it provides a normal modulation technique that employs adaptable duty-cycle and parameter which affects to ensure perfect ZVS. Furthermore, the grid voltage THD is considerably reduced using the 4th harmonic injection approach. The suggested modulation's efficacy was tested on a 3.84-kilowatt model with a 100-240 Volts AC input and a 460-800 Volt storage battery. In comparison to prior efforts, the efficiency of the reduced voltage grids has risen by 2.3 percent.

H. R. Gholinejad, J. Adabi and M. Marzband (2022) have proposed a smart charging approach for DC EV chargers in home energy hub. They have proposed a small bidirectional charger using photovoltaic and battery storage. They have practically implemented a two level Hierarchical energy management system in the laboratory for high energy hubs with plug-in electric vehicles. They have defined the state of charge of both EV and Battery storage using Bellman-Ford-Moore algorithm which is confirmed by simulation and experimental results.

I. Kougioulis, P. Wheeler and M. R. Ahmed(2022) have combined the features of On-Board Charging and Advanced power management in a single converter, this research offers an improved isolation of triple-active bridge (TAB) transformers. The suggested converter has a

straightforward design and can charge either High Voltage (400V) or Low Voltage (12V) batteries at the same time. Moreover, using the converter's five variance, a conducting loss-minimization technique is given, with the goal of improving the converter's performance by lowering the RMS power in the LV bridge.

J. H. Choi, J. Y. Lee, and H. M. Kwon (2022) have presented the viability of a silicon-carbide (SiC)-based bidirectional converter charging for electrical vehicles (EV). The bidirectional converter architecture is the easiest, however the transformers leakage current has a significant impact on the circuit current loads. An effective circuit and an active shunt resistor circuit are used between ends of the transformers to minimise device voltage stressors by recovering stored energy inside the transformer’s leakage current.

M. Y. Metwly, et.al. (2020) have suggested that there is a monitoring control for an integral onboard chargers with an asymmetric nine-phase architecture. Today's off-board charger apps include network limits and interface of the system into the charging cycle via a wide range of communication channels. Due to the above, demanding side control for Electric vehicle charging has been put into practise. This paper is a move in the right direction in terms of presenting the argument for OBC registrations. Although it may seem reasonable for the distribution network administrator to regulate off-board charges, there is uncertainty over the benefits of OBC. Additionally, to improve the user experience, the suggested integral on-board charging is control system based and the recharge rate is managed via a mobile application using IoT technology.

M.F.M. Elias and A.K. Arof (2005) have researched in the application of a Li-ion charging station for Li-ion batteries linked in series. Ten Li-ion batteries with a total output of 6Ah as well as a voltages of 4.2V each one is employed. The practical findings demonstrate that rechargeable batteries based on consistency have a charging time. The final balancing of each of the batteries has already been achieved by using variables required to charge time depending on the disparity between the lowest and highest voltages when recharging in a consistent charging method. Thus, this contributes to maintaining the life span, performance, and capacities of the Li-ion batteries through connected series.

P. Ahmad and N. Singh (2022) have proposed on board and off board EV charging schemes on the basis of voltage regulation and state of charge (SOC). They have designed an adaptive controller which has predefined voltage reference to be compared with EV Voltage at the point of references. Battery SOC, owner’s required end of charge and voltage comparison are the

factors used to control the charging rate and voltage supplied. The authors have also performed various simulations using bidirectional controllers. Bidirectional controllers charge the EV and supply power to the grid back from EV whenever the grid is falling short of power. Inverter converts DC from EV into AC. The authors have validated their proposed controller using extensive simulations.

S. Dutta, et. al. (2022) have provided a single bridgeless Cuk-derived power quality corrected (PFC) converter with a lower operating count for on-board electric vehicle (EV) charging. This suggestion is unique in that it designs and operates the converter's yield inductance in non - continuous current phase for the entire energy range to achieve PFC normally at ac mains, eliminating the need for voltage level and load current sensors, lowering converter costs, and improving energy capacity as well as controlled rectifier durability to high levels of noise.

S. K. Nayak(2019) has stated that use of electric vehicles as an evolutionary idea for smart city projects. The charging system of the electric vehicles can be defined in two different categories which include on-board and off-board along with unidirectional and bidirectional power supply capacity. The unidirectional transmission simplifies the interconnection issues and hardware requirements are limited and bidirectional supports the injection of energy of the battery back to the grid. This research paper discusses the different types of fast charging and topologies in brief.

S. P and N. G.K(2022) have reviewed various Electric Vehicle battery charging methods on the basis of power transfer, infrastructure requirements, power levels and power flow directions. For different power transfer methods inductive charging reduces the risk of shock because of electrical isolation but conductive charging gives high efficiency. The On board charging system has power restrictions as it has to meet size, weight and cost constraints. Off board charging system is a fast charger and requires more input power at one go. Unidirectional charger uses less hardware to reduce interconnection issues and delays battery. Degradation whereas bidirectional chargers support energy back transfer to the grid whenever required.

W. Xiang, et.al. (2014) have found that the effects of the coordinating algorithms and EV charge are examined using a prototype software. The simulations generated by the application offer a detailed overview of the power usage patterns of the families. This article offers some findings, analyses, and conclusions that show how the suggested method might be applied to research the impacts of policy choices. To lessen the effect of charge EVs, we applied the versatile smart home products grid modelling framework that was suggested. More

specifically, we discovered the best threshold value to maintain a steady drain on the electricity network without compromising user satisfaction. The particular outcome is dependent entirely on the simulated settings employed in this case. In current and upcoming projects, we'll hone the tool even further and use it to tackle a variety of different issues.

X. Jia, *et.al* (2017) have analysed the increasing popularity of conversion of electric vehicles into grid or microgrid, providing back up power at the time of discharge. The electric demand is managed by the vehicle-to-home(V2H) applications which in turn are constructed from electric vehicles (EV) to provide power supply at times of emergency. Voltage and frequency are regulated, which offers spinning reserves for management of electrical demand. But the use of EV charges in V2H applications led to low conversion efficiency due to complicated control algorithms caused by DC/DC and DC/AC conversion stages. The effectiveness of novel EV charger for V2H applications is verified. It can give AC voltage at the output with only single-stage power conversion. The battery voltage of the proposed single-stage EV charger is boosted along with providing 1-phase, 3-phase and DC loads which are to be fed with single stage conversion. The performance evaluation results have proved the effectiveness of the proposed strategy to work with variable loads.

Z. Zhang, *et.al* (2022) have proposed For GaN-based SRs, this study proposes a fine-controlled synchronised gate driving technique. A new discharge sensor circuit is formulated to overcome the difficulties of the over and oscillations induced by high voltages dv/dt. The 3 Si-based supplementary switches are powered solely by the SR's basic simple drive voltages, making the circuit simple, dependable, and minimal cost to operate. Based Secondary Rectifier in EV On-Board Charger, IEEE- The smart sensing circuit's specific working concepts and design problems are also examined. Furthermore, the adaptable SR on-time adjusting technique is used, which eliminates the effect of looping stray inductance and transmission delay in the route and precisely approaches the Set-Reset zero current switching instant.

2.1 Gaps in Study

- For the Indian market, there is a huge gap in terms of charger efficiency in between slow and fast charger.
- The space in the vehicle is limited but the requirement of energy is increasing, so the smaller circuits are needed to provide efficient power the battery.
- The AC-DC PFC must transfer high power density at higher efficiency.

- The switching losses in high frequency back-end converter are high.
- The PFCs are missing functionality of IoT, so tracking their functioning is difficult.
- Additionally, regular use of fast DC chargers can negatively impact battery life due to high C-rates.
- The initial installation cost of EVSE is very high, due to non-availability of equipment in India.
- The environment friendly power sources are not being used to supply power to EVSE to charge the EV.
- There is huge gap in the concept of Bi-directional EVSE, which would require multiple PFCs, which is not being so widely used.
- The concept of battery swapping is just in theory as it requires huge infrastructure to swap the huge batteries out if the EV

3. DESCRIPTION OF TOPIC

For any electric vehicle the source of power, there is an on-board power storage device, most used is battery. The battery is charged with electricity from any of the conventional or non-conventional sources. The schematic of an electric vehicle is shown in the figure 1. The power electronics converter is used to match the ratings of EV battery and the motor. Motor can be either an AC motor or DC motor, therefore the converter used would be a DC-AC. Battery works on input and DC output. The major challenges in the EV are limited range. Size of battery, cost and range all are directly proportional to each other.

3.1 Battery Study

The foremost step of designing an EV is to design a preferable and suitable battery responsible for the transmission of EV. The battery must be able to satisfy the need for a long working cycle and life along with fulfilling the electric specifications of operating voltage and power. Battery should also have desired power and energy densities.

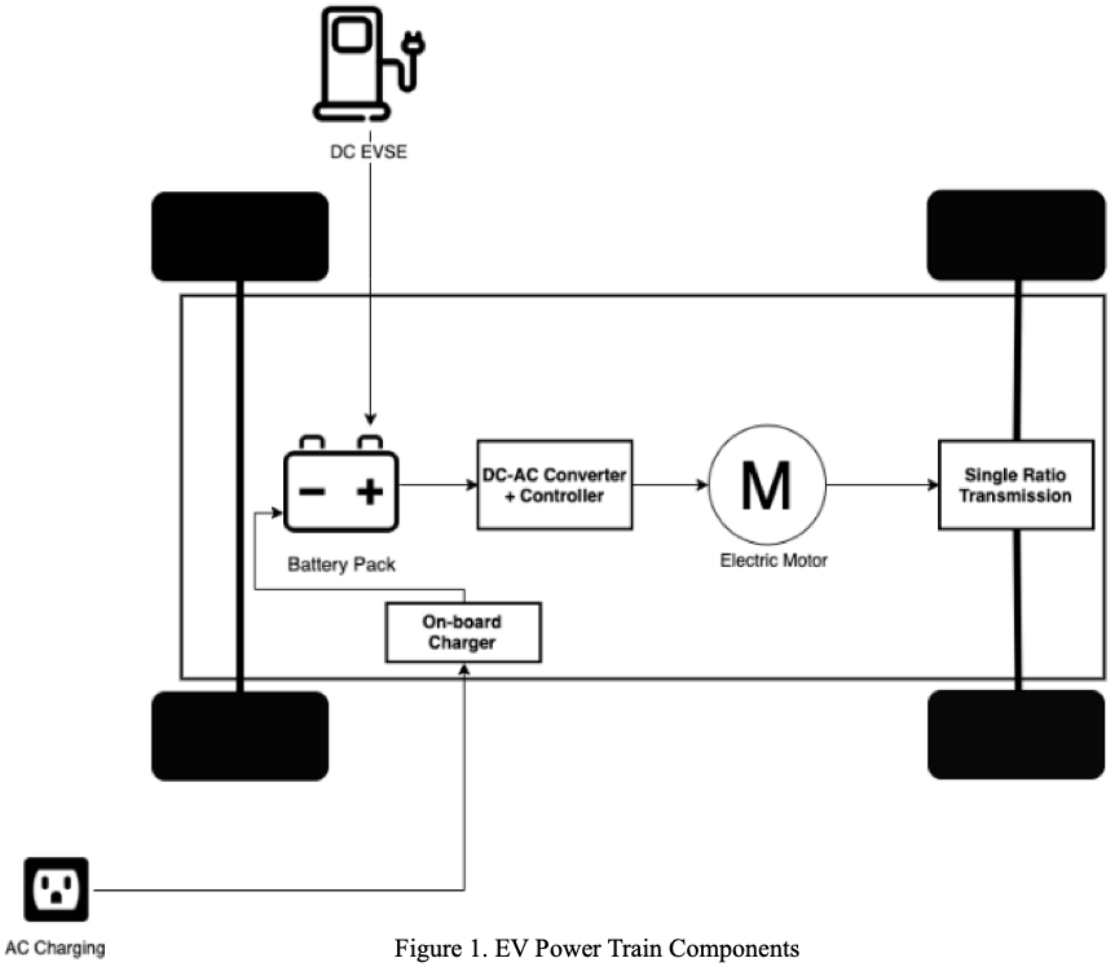


Figure 1. EV Power Train Components

In automobile industries the most used batteries are made up of Lithium-ion. In comparison to Ni-cd batteries, Li-Ion batteries have twice the energy density at same load characteristics. A single cell Ni-cd battery is 1.2 V, Lead acid battery is 2V and Li-ion is 3.6 V.

The li-ion battery provides almost constant power for 80% of its discharge cycle, therefore it can be said it has a fairly flat discharge cycle.

Li-ion battery weighs less in comparison to Ni-cd battery. For example, power output of a 20 kWh battery. Ni-cd weighs 275 to 300 kg whereas Li-ion batteries weigh roughly 160kg.

Despite the advantages, the disadvantages of Li-ion batteries is that the battery is costly and flammable. The life cycle is also limited between 400 to 700 lifecycles. The safety threat can be removed by moving to a Lithium ion phosphate battery whose life cycle is also about 1000 cycles.

3.1.1 Battery parameters

The capacity of the battery is defined in kWh, as the maximum amount of power the battery can produce in 1 hour. Output Voltage, V volts battery the battery capacity in Ah can be calculated as eq. (1)

Battery capacity in Ah= Battery capacity in kWh/ Output Voltage in V (1)

State of Charge (SOC)

The measure of percentage of discharged battery is 0% and fully charged battery is 100%. The voltage output from the battery does not stay constant throughout the discharge cycle. At a fully charged battery the output available would be more than ‘V’ volts and as the battery discharges the output voltage may reduce more from defined V volts too. In designing an EV motor controller works according to variable output voltage.

The **C rate of the battery** is defined as its charging or discharging rate. It is the equivalent to the capacity of a battery when it is fully charged in one hour.

If the capacity is X kWh, then 1C Charge or 1C discharge would be X kW. The rate of charge or discharge of the same battery in half (1/2) hour would be 2C. Similarly, Charge Rate in ¼ hour would be 4 C. If the same battery takes 10 hours to charge the rate would be 0.1 C and in 5 hours charge rate would be 0.2 C.

When the battery is charged at around 0.1C, 0.2C or up to 0.5C rate the process is called slow charging. The rate near 1C or greater than 1C is said to be fast charging.

Depth of Discharge (DOD) For the long life of the battery, the battery is never fully charged or discharged. Certain energy level is left at the top and the bottom. The usable energy is referred to in the depth of discharge or DOD. DOD is always less than 100%.

The life range battery reduces with each charging cycle. If SOC of battery at any instance is 'S' and DOD is 'D'. 'S' and 'D' end of the life if the battery can be calculated by eq (2)

$$\text{Usage capacity- DOD} \times \text{SOC} \times \text{C Rate}$$

$$= D \times S \times C \qquad (2)$$

As D and S are always less than 100%. Therefore, the usable capacity is always less than 100% C.

3.2 Battery chargers for EV

EV battery charger plays a very important role to maximise the capacity of the battery. The features of a dependable charger are its efficiency, reliability, weight, cost, charging time and its power density. These characteristics of the charger are dependent upon the components, switching and control algorithms used in micro designing and implementation of the charger.

The charger can be divided into two stages. At the first stage AC grid voltage is converted into DC of high-power factor and low total harmonic distortions. At the second stage the charging voltage and current are regulated on the basis of the charging method used.

The charger can be unidirectional or bidirectional. Unidirectional charges vehicle from a grid or also known as grid to vehicle (G2V). Whereas, bidirectional chargers can supply power to the grid from vehicle or power shortage at grid along with charging. This process is vehicle to Grid (V2G).

The chargers are designed with in-built safety features. Either charge circuit interrupting device (CCID) circuit or ground fault circuit interrupter (GFCI) are to be built inside the EVSE to prevent the leakage current in the equipment. The standards for the same are given by *UL 943 Standard for Safety*…, *UL 2231-2 Standard for Personnel Protection Systems*…, UL *2231-1 Personnel Protection Systems*…, *2011 Edition, National Fire Protection*…, *NFPA 70 National Electrical Code 2011*…, J1772, SAE Surface Vehicle Recommended Practice…

3.2.1 Charger infrastructure and power levels

For a charger, the important features are location, charging time, cost, effect on grid and the amount of total power that can be transferred. By deployment of proper charger infrastructure

and electric vehicle supply equipment (EVSE) many issues like charging station standardisation, charging time, grid load distribution and demand policies etc can be addressed.

On the bases of power levels, the chargers can be divided into 3 categories as described below:

Level 1 charging

According to US standard, level 1 charging is done using a 120 V single phase outlet. Charging outlet is connected to the EV port via standard J1772 connector. Vehicle needs to be charged at least overnight. Level 1 charging is the slowest charging method. It does not require any extra infrastructure. The supply equipment is connected to the on-board charger mounted inside the Electric Vehicle which ultimately charges the battery. The maximum of 2 kWh provided to EV using level 2 charging EVSE.

Level 2 Charging

According to the US standard, level 2 EVSE uses 240 V outlets. In India and most of Europe, level 2 charger is used. It is also connected to an on-board charger which uses JAE1772 level 2 connector for charging an EV. It is a semi fast charging method. It can be set up at home or office for charging the EV. Level 2 EVSE can charge the vehicle at different power levels by withdrawing up to a maximum of 80 A. The working range lies in between 3.3 kWh to 20 kWh

Level 3 Charging

Level 3 charging is the fastest charging and takes very less time to charge an EV may be charged in as less as one hour. The range of level 3 EVSE starts from 20kWh and rises to 200 kWh. 100 kWh and above fall in the category of ultra-fast chargers. It is an off-board charger offering DC power. Government and private companies are setting up level 3 chargers for charging EVs.

3.2.2 Standardisation in EV Charger

Gird and EV connector needs to be standardised to maintain the uniformity. Charging Power and voltage limit are to be standardised. The charger would not work either if the EV needs more power or if the input is higher than the capacity of the charger. Energy operators need to be communicated from time to time for the updates and supply communication is needed with EV's Battery to understand its requirements and supply available at the charger.

3.2.3 On board Charger

On board Chargers are AC-DC rectifiers i.e., it converts AC-DC. The onboard chargers do not require communication with the grid or vehicle regarding the metering. It is specified by voltage of battery, battery range and output current. Voltage and current talks about the maximum power available for the EV to be charged using OBC. Efficiency and Power factors also play an important role. More the efficiency, the less the energy lost in the form of the heat dissipation. Safety and environmental aspects are to be standardised.

3.2.4 Off board Charger

The off-board charger is the charger that directly charges the battery. This type of charger provides DC directly to the battery bypassing the on-board charger. The Off-board charger is usually a level-3 charger and charges the EV faster than level-2 chargers. The size of the off-board charger is big therefore it must be mounted on the wall with a dedicated input supply from the grid. It is generally referred to as a charging station. The input received at the charger is AC which it rectifies into DC. It receives a signal from the vehicle when it gets connected and charging starts after getting confirmation. In the case of a private charger owner, the owner has the access to start the charging whereas, at the charging station the charging is started by fulfilling the formalities at the station by the user like giving the details and pre-payment for the charging.

Charging modes of Chargers

An EV Charger works in either of the two modes.

1. Constant current mode.
2. Constant voltage mode.

In constant current mode, a feedback loop is provided to maintain the output current constant by adjusting the voltage. In constant voltage mode, the voltage is maintained at a constant level, even if the value of the current falls to zero.

Software communication is done in between EV and charger to decide the mode of operation. If the current is adjusted in CC mode charging rate can be controlled along with preserving battery life. The Chargers with the low efficiency and poor power factor are cheap at the time of purchase but waste a lot of power and turn out to be more expensive in terms of money and time.

The needed charger should have good efficiency and power factor. The overview of working of on-board charger is.

- AC signal is rectified into DC signal.
- Frequency of the signal is increased.
- Small sized high frequency transformers either increase or decrease voltage level to the desired level.
- Signal is rectified to get the desired DC voltage.
- The entire process is controlled by software.

3.3 Power Factor Correction

The current pulses flowing through switching power supplies without power factor correction are short, but high intensity, which can be smoothened out by using either of active of passive techniques. These techniques increase the power factor by reduce input RMS current and further apparent current. This technique is called power factor correction (PFC). The PFC alters the input current in such a way that maximum output power is received at the output. The load at the supply should ideally be as pure resistor, i.e., there should be no reactive power and the current and voltage waveform should be in phase with each other, which is not the case practically.

Ideally, all the AC supplied to the circuit should be used productively, which is not practically possible when the current and voltage waves are not in phase with each other, thus some of power gets lost in the transmission. Therefore, the power generation companies must bear the loss of transmission losses and generate high amount of power than needed to fulfil the demand. The cost is ultimately paid by the users along with increasing the global warming.

Here, power factor correction plays very vital role, as the PFC circuit is implemented in such a way that power factor is desired as 1, or even in most or applications power factor of 0.95 is accepted. Commonly the PFCs are divided into two categories: Passive PFC and Active PFC.

Passive PFC: in this correction method, a series resonance circuit is created at the AC input using the capacitor and inductor. The circuit created it pretty much inexpensive but provides an effective PFC. This circuit mostly used at lower power supplies, 100W or lesser. The passive PFCs are efficient, inexpensive, robust, reliable, and simple to construct but can be heavy and

big due to the size of inductor. Passive PFCs are compatible to only limited range of input voltages and there is less voltage regulation.

Active PFC: in this correction method, there is a control circuit which measures the input current and voltage and changes the duty cycle and switching time to make sure that both the input current and voltage ate in phase. Theoretically, automatic AC input voltage correction leads to power factor of more than 0.95 and operates on wide range of voltages. The circuit is controllable with more flexibility at the same time. The circuit requires some extra components, which make it complex and higher in price. The circuit need more filtering and high frequencies can enter the line.

For BEV or PHEV's PFC is used in charging infrastructure. Most of them are charged at low charging level around 1.5kW, 3.3kW and 7.2kW using single phase power supply. When vehicles are put to charge during peak hours, the utilities face troubles, therefore the PFC is needed so that the load of the utilities can be reduced somehow. The input current harmonics must fulfil the regulatory standard for example IEC 61000-3-2 (International Electrotechnical Commission). Therefore, the PFC is mandatory in EV charging circuit.

For EV charging circuit, active PFCs are used in the chargers to control the harmonic distortions as the power supply is always greater than 100W. The methodology of PFC can be classified into two classes: single stage and two stage methodologies. Single stage PFC methodology is more suitable be for batteries like lead acid batteries which consume lower power as low frequency ripples are present in large number at the output current. Whereas, for EVs with Li-ion batteries two stage PFCs are used as the power rating is comparatively high. Firstly, AC in converted into DC using AC-DC converter where AC-DC PFC is used, then DC-DC converter is implemented to generate regulated DC output from rectified DC output.

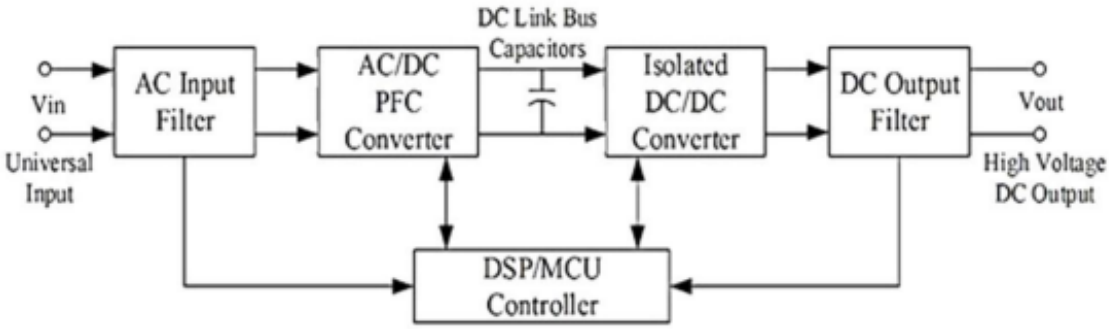


Figure 2. Block diagram of a universal input two stage battery charger for EVs

The EV motor works on the basis of speed torque characteristics, so there is need of soft switching for PFCs so that the loss during charging the battery is as minimum as possible. Two types of switching are considered in the PFC. Zero voltage switching (ZVS) and zero current switching (ZCS). ZVS turn on the device at zero voltage instant and ZCS turn off at zero current instant.

3.4 Internet of Things (IoT)

The most widely used technology these days is the Internet of Things (IoT) in which major things are connected using the internet. IoT has a huge range of applications such as defence, healthcare, supermarket, transportation and so on. For the optimisation of sensor nodes and devices are embedded with open-source standards for wireless communication such as Bluetooth, Wi-Fi and RFID. Internet technology is constantly progressing, and cost is reducing, which makes it more convenient to integrate internet technology with home automation systems. Some of the devices used in the household can reduce the manual work when they are operated remotely. For example: if an Air Conditioner and refrigerator are connected using IoT, the owner can set the temperature before reaching home or even turn it off remotely. For the Electric Vehicle also, IoT is playing a vital role. The manufacturers are building the IoT inside the vehicle so that all the sensors, and sensor-controlled features can be studied and controlled remotely along with detecting the tiniest of the error. For the EV charging stations IoT applications are being built compatible with EV which can tell the owner about the battery status and how much it can run till it finds the next charging station. Such can be the case for Electric Vehicle charging too. The IOT needs to set up at the PFCs of the charger to monitor the functioning of PFCs. If anything goes wrong at the PFC, it could be easily detected, and the efficiency of charger would not be compromised.

4. Motivation

With the depletion of fossil fuel reserves and climate change alternatively fuelled vehicles are the need of the hour. Electric vehicles are one of such alternatively fuelled vehicles. Most of the EVs available have short range and all the properties in India are not level 3 charger friendly but are Level 2 Electric Vehicle Supply Equipment (EVSE) friendly. So, the most used charger are on-board chargers which would convert the AC into DC to charge the battery. Level 2 EVSE is also less expensive than level 3 charger though the charging time is high, but the EV can be charged overnight at home or office at the convenience of the owner. The EVs are charged on the basis of the C-rate of the battery. The charging capacity of the EVSE is maintained to charge the battery without degrading the charging capacity. If the EV is charged regularly at the charging rate greater than the C/2 rate of the battery, it would quickly deteriorate the battery capacity. Keeping in mind the mindset and restrictions in availability there is a need to build a higher capacity of PFCs in chargers which would be available to people at an affordable price without compromising battery capacity. IoT enabled charger with PFCs is needed to check the charger remotely. Whenever a person use the personal EVSE at not so personal space such as society parking, office parking, or any other place where charging stations are not available but the sockets are there, where one can charge with personal charger, there is the risk for the owner of getting any kind of glitch, either in power or voltage that would hinder the charging. In addition to it, IoT can also inform the charging functionality to both user and manufacturer so they can take the maximum output from the EV charger and can also detect faults if any occurs.

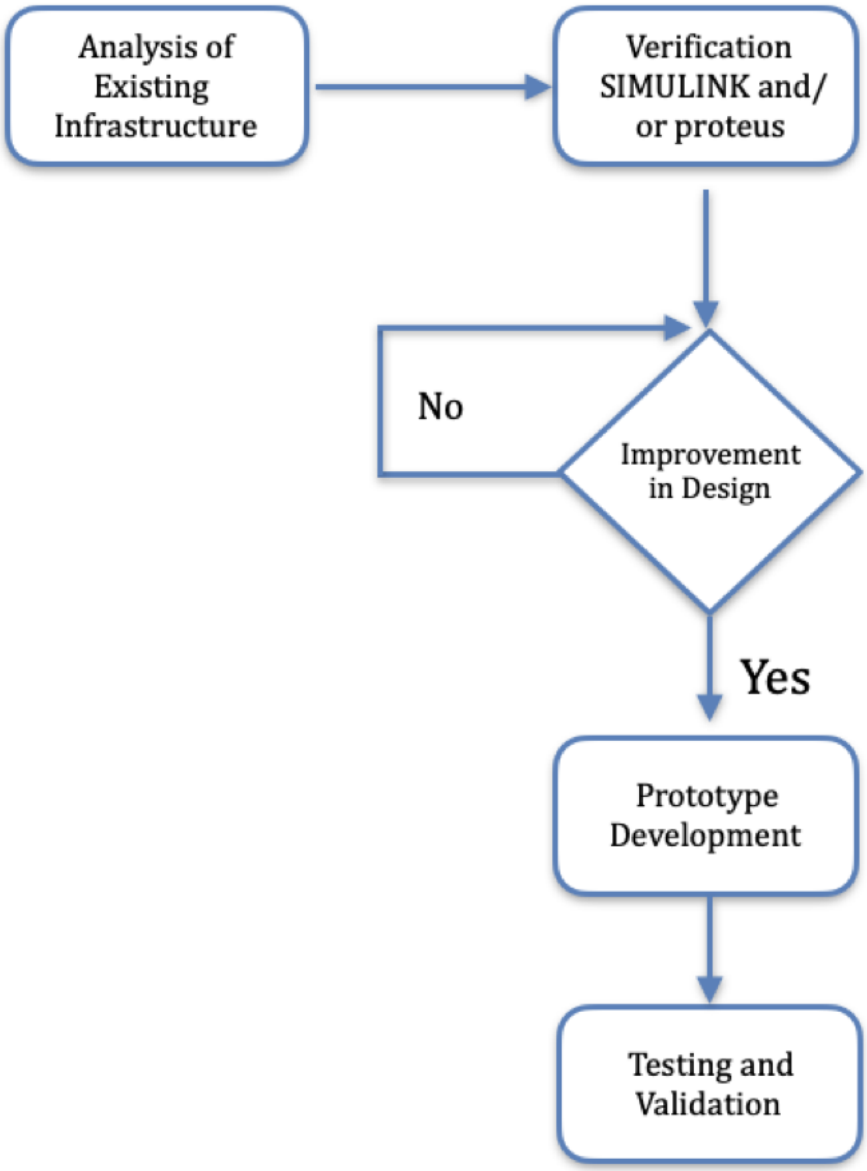
5. Objective

The objectives of the proposed work for an Electric Vehicle Supply Equipment (EVSE) are

- To design and analyse an EV charger with different PFC.
- To integrate IoT in the PFC, to monitor the functioning of charger.
- To develop MATLAB- SIMULINK and/or PROTEUS module for EV charger with PFC

6. Methodology

The process or research and development will be divided in 4 different phases. In first phase, the different existing infrastructure will be analysed, and corresponding circuits will be developed in SIMULINK and/or PROTEUS. In second phase, the existing circuits will be modified to obtain the desired results and results will be verified using SIMULINK and/or Proteus. Further in phase three, the iterations will be performed in design and verifying the results, till the desired results are achieved. In phase four, the prototype will be developed. In final phase the developed prototype will be tested and validated.



7. Expected Outcome

The existing model and algorithms will be simulated on MATLAB- SIMULINK. New developer module for Electric Vehicle chargers with different PFCs will be developed in SIMULINK. Proteus will also be used to perform the experimental investigations. The state-of-the-art prototypes will be developed, and the comparative studies will be carried out. Since IoT plays a key role in our research, the traditional sensors and circuitry will be developed, tested, and implemented, and the performance of the proposed circuit will be demonstrated. Along with it, the conceptual aspect till now such as implementation of IoT in the design of EV charger with different PFCs will be implemented. The proposed and existing models will be compared on the basis of compactness, output effectiveness, charging duration, per unit price, and gross margins to show the achievement of the above-mentioned research objectives.

Further, feasibility in the Indian market will be explored along with the implementation plan.

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Design and Analysis of Electric Vehicle Charger with Power Factor Correction

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ABSTRACT

The world is rapidly using its reserves of natural fossil fuel amongst which the automobile industry is the fastest user. Along with the deletion of fossil fuel it has led to global warming. There is dire need to move from the use of fossil fuels to alternative fuels to run the vehicles. Electricity powered vehicles are proving to be a boon for the same cause. For the efficient working of electric vehicles, there is need of efficient storage devices such as fuel cells, solar cells, batteries, ultra-capacitors etc. Rechargeable Batteries are most used energy storage devices used in EV industry. As the batteries are to be charged after the power from them is drained, there comes the use of Electric Vehicle battery chargers to charge the EV battery. EV charging can be classified into 3 different levels of charging. Level-1 is the slowest level of charging common in North America and Japan, level-2 is available in most of Asia and Europe and little faster than level-1 charging, and 3rd level is fastest DC charging and the most expensive one too. There are different categories of EV chargers i.e. On-board chargers and Off-board chargers. Off-board chargers need specific infrastructure and high input power supply to charge the EV batteries directly through DC supply. Whereas the On-board

chargers do not need special infrastructure for charging an EV except for the Electric Vehicle Supply Equipment, which supplies the AC to the EV's On-board charger to further charge the EV battery. The continuous research is going on for long ranged EV batteries. With the development of fast and long-range batteries, there is a need for fast and affordable PFCs for the chargers. The PFCs would control the harmonics produced in the circuit at AC-DC or DC-DC stage of chargers. The PFCs would keep the input current in phase with input voltage so the power factor of the circuit would remain almost 1, which is practically not possible so the nearest desirable output is 0.95 power factor. Implementing IOT at PFC level would help to control and monitor the circuit even better.

Keywords: EV charger, PFC EV charger, IOT EV charger